"Design of a Propulsion Motor and Associated Controller for Underwater Platform"

SHORT SYNOPSIS

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DOCTOR OF PHILOSOPHY

to

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by

Arun Singh
Registration number: **18/PhD/74**

Under the supervision of
Dr. Anita Khosla
Professor, Department of Electrical & Electronics Engineering
FET, MRIIRS

FACULTY OF ENGINEERING & TECHNOLOGY

MANAV RACHNA INTERNATIONAL INSTITUTE OF RESEARCH & STUDIES

SECTOR-43, SURAJKUND –DELHI ROAD, FARIDABAD – 121001

FACULTY OF ENGINEERING & TECHNOLOGY

Certificate

I hereby declare that the short synopsis on "Design of a Propulsion Motor and Associated Controller for Underwater Platform" is being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Electrical & Electronics Engineering under faculty of Engineering & Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2021-2022.

It is a bona fide record of original work carried out under the supervision of Dr. Anita Khosla. The work has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

Asingh

(Arun Singh)

Reg No: 18/Ph.D/74

Signature of the Supervisor
Dr. Anita Khosla
Professor, EEE Department, FET, MRIIRS

(Chairman, DRC)

Chairperson, CDP

ABSTRACT

The outcome of the research work shall lead to the Design of a Propulsion Motor and Associated Controller which can operate in submerged state up to a depth of 1000 meters and provide 1MW output of shaft power for the propeller at 800 rpm to drive the Underwater Platform which will be used for utilising maritime resources.

Human beings live on the land and have been exploring water bodies for ages to utilise maritime resources available on surface and underwater for enriching their community life by using various types of man-made underwater platforms i.e. Ships, oil rigs, boats, submarines etc. These platforms are either stationary or moving. All moving platforms are driven by propulsion systems e.g., Nuclear Power, Diesel Engines, Fuel cell / Air Independent Propulsion (AIP), electrically driven motor generating thrust for movement using propeller / water jet. In this research, comparative analysis of various types of existing Electric motor based propulsion systems and controllers mounted on different underwater platforms with their limitation will be deliberated. Propulsion System using Multiphase permanent magnet AC motor mounted outside underwater platform submerged in water along with associated controller for driving multiphase PMAC motor is proposed to be designed. Also, remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt is planned to be implemented in the design.

Key words: Propulsion Motors for Underwater Platforms, Multi Phase Motors, Controller for Propulsion Motor, Propulsion Control using IEEE 802.3 bt

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1. Introduction

1.1. Earth comprises land and water. 71% of earth's surface is covered with water bodies i.e., Sea, Ocean, Rivers, Lakes, Reservoirs which are rich in maritime resources e.g., Crude oil, minerals, fishes, convenience of navigation etc. Human beings live on the land and have been exploring water bodies for ages to utilise maritime resources available on surface and underwater for enriching their community life. Also, waterways are used for navigation and transportation. Therefore, efforts are made by people to explore, protect and utilize maritime resources using various types of platforms / vehicles given in table 1 below which can be classified as Submarines, Underwater torpedoes / Missiles, Ships, Boats, Autonomous or Remotely operated underwater vehicles, Sub Sea Robotic crawlers, Oil exploration vessels, Rigs, Sea floor stations, Floating Platforms etc. The Platforms may be manned or unmanned, moving or stationary depending upon the usage and operate at surface or underwater.

SNo	**Platform / Vehicles**	**Manned / Unmanned**	**At surface/ Underwater**	**Exploration / Research / Security / Transportation**	**Stationary / Moving**
(a)	Submarines-Military	Manned	Underwater	Security / Protection of Maritime Resources	Moving
(b)	Submarines-Research	Manned	Underwater	Research of Maritime Resources	Moving
(c)	Submarines-Tourist	Manned	Underwater	Tourism	Moving
(d)	Atmospheric Diving Suit	Manned	Underwater	Security / Research /Tourism	Moving
(e)	Underwater Torpedoes	Unmanned	Underwater	Security / Protection of Maritime Resources	Moving
(f)	Underwater Missiles	Unmanned	Underwater	Security / Protection of Maritime Resources	Moving

SNo	Platform / Vehicles	Manned / Unmanned	At surface/ Underwater	Exploration / Research / Security / Transportation	Stationary / Moving
(g)	Ships / boats	Manned	At Surface	Security / Protection of Maritime Resources Transportation of Men & Material	Moving
(h)	Autonomous underwater vehicles (AUVs)	Unmanned	Underwater	Exploration, non-Destructive testing & Inspection of underwater platforms	Moving
(i)	Remotely operated Vehicles (ROVs)	Unmanned	Underwater	Exploration, non-Destructive testing & Inspection of underwater platforms	Moving
(j)	Hybrid Aerial Underwater Vehicles	Unmanned	Air / At Surface / Underwater	Exploration, non-Destructive testing & Inspection of underwater platforms	Moving
(k)	Subsea Robotic Crawler	Unmanned	Underwater	Exploration, non-Destructive testing & Inspection of underwater platforms	Moving
(l)	Oil, Gas & pipe exploration vessels	Manned	At Surface / Underwater	Exploration of Oil & Gas supplies	Moving

SNo	Platform / Vehicles	Manned / Unmanned	At surface/ Underwater	Exploration / Research / Security / Transportation	Stationary / Moving
(m)	Oil rigs	Manned	At Surface / Underwater	Exploration of Oil & Gas supplies	Stationary
(n)	Seafloor Stations	Manned	Underwater	Exploration of Oil & Gas Supplies	Stationary
(o)	Floating platforms	Manned	At Surface	Exploration of Oil & Gas Supplies and support for navigation	Stationary
(p)	Anchored Platforms / Tow fish	Manned	At Surface	Exploration of Oil & Gas Supplies and support for navigation	Stationary / moving

Table 1: Underwater Platform and their Attributes

1.2. Stationary platforms don't have their own propulsion system for navigation and are positioned in desired location with the help of ships / boats. However, moving platforms have their own propulsion systems for navigation & operation. All Moving Underwater Platforms and Vehicles will be referred as Underwater Platforms in this paper. All Underwater Platforms can be mechanically driven by propulsor e.g., Nuclear Power, Diesel Engines, Fuel cell / Air Independent Propulsion, electrically driven motor etc generating thrust for movement using propeller / water jet.

1.3. Nuclear powered propulsor gives total independence to underwater platform for movement inside water without coming to surface. That means underwater platform can operate in submerged state under the polar ice cap region, move around the globe while remaining submerged in water, remain hidden under sea in all respects except when it is required to communicate with outside world. Diesel–electric propulsion system provides mechanical quietness and compact mechanical spaces when operating submerged on batteries, but in the due course come to the surface for charging of batteries. AIP promises

a combination of advantages – independence from surface, reduction in radiated noise and smaller size [Stan Zimmerman 2000].

1.4. Propulsion systems mentioned earlier drive propeller directly or through electrically driven motor. In this research, electrically driven Propulsion motor will be studied. These propulsion motors can be mounted inside / outside underwater platforms whose features are given below:

1.4.1. **Motor Mounted inside Underwater Platform.** Following type of propulsion Motors are generally mounted inside underwater platform for propulsion:

1.4.1.1. Permanent Magnet Synchronous Motor (PMSM) using variable frequency drive with DC or AC input power supply.

1.4.1.2. Induction Motor using variable frequency drive with DC or AC input power supply.

1.4.1.3. DC Motors operated by DC Generators in Snorkeling mode or batteries in underwater state.

1.4.1.4. High Temperature Super Conducting (HTSC) synchronous motor using variable frequency drive with DC or AC input power supply.

1.4.1.5. Propulsion Motor and associated controller are the key component for driving the underwater platform. Diagram of Propulsion System with Propulsion Motor and Controller Mounted inside Underwater Platform and Propeller mounted outside is given in figure 1 below.

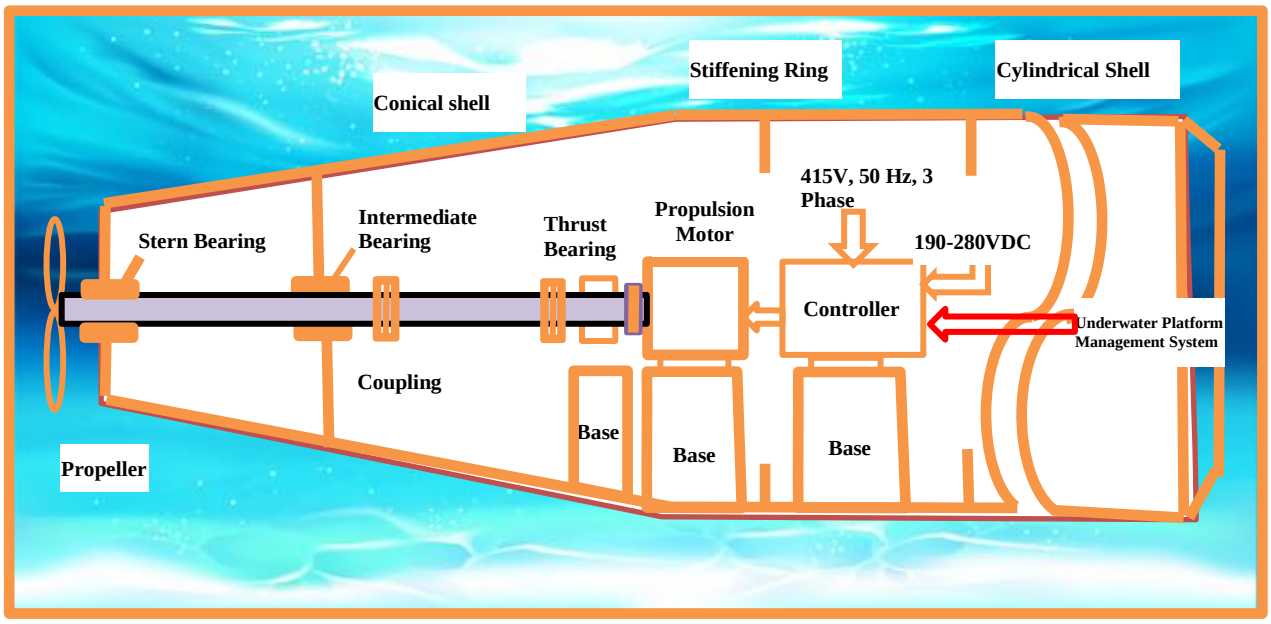

Fig 1: Propulsion System with Propulsion Motor and Controller Mounted inside Underwater Platform and Propeller mounted outside

1.4.2. **<u>Motor Mounted outside Underwater Platform</u>.** DC motors are generally not used when submerged in water due requirement of commutator. Following types of propulsion motors are generally mounted outside underwater platform for propulsion:

1.4.2.1. Permanent Magnet Synchronous Motor (PMSM) operated using variable frequency drive with AC input power supply or DC supplies from batteries.

1.4.2.2. Induction Motor using variable frequency drive with AC input power supply.

1.4.2.3. Diagram of Propulsion System with Controller Mounted inside Underwater Platform and Propulsion Motor and Propeller mounted outside is given in figure 2 below.

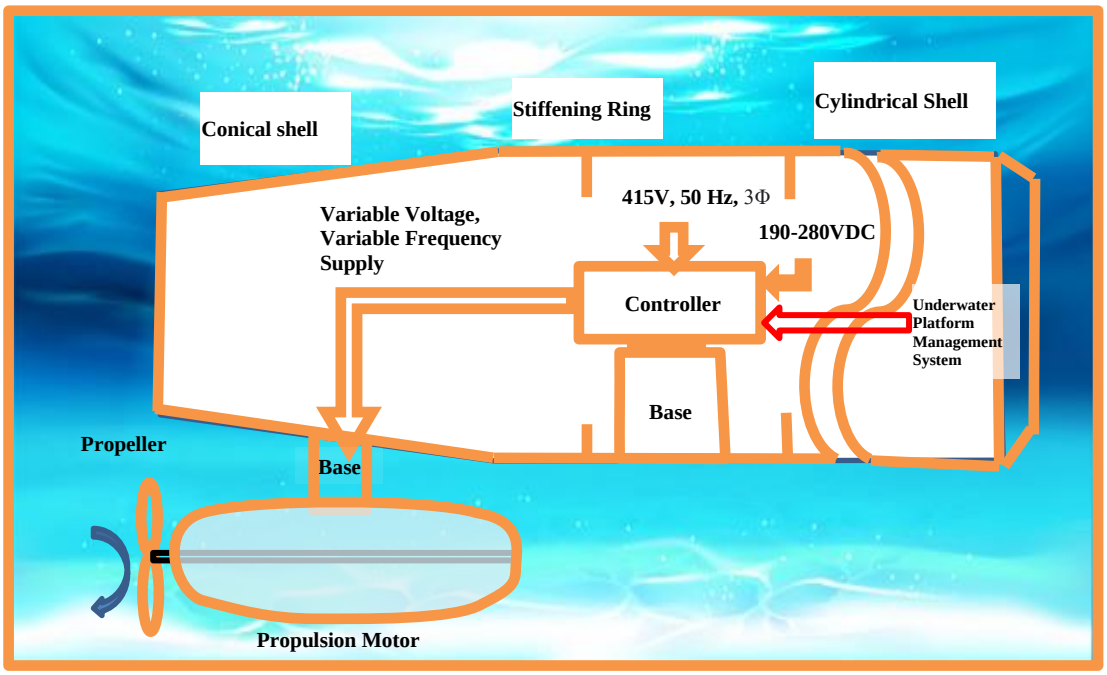

Fig 2: Propulsion System with Controller Mounted inside Underwater Platform and Propulsion Motor and Propeller mounted outside

1.5. **Propulsion.** The science of driving platforms / vehicles is called Propulsion. Underwater platform is driven by the propulsion system which provides the force to accelerate it and balances other forces opposing its motion. The majority of advanced Marine propulsion systems develop force, called thrust, along the desired direction of movement across water by adding energy to a working fluid which changes its momentum. Mechanical system consisting of an electric motor or turbine / engine turning a propeller are used for propelling majority of the advanced submarines, ships, boats and other vessels in the water bodies. Evolution of marine propulsion is given below [Komerath, Narayanan M 2018]:

1.5.1. The first form of marine propulsion was in the form of paddles, and sails which used manpower for their operation.

1.5.2. In the beginning of 19th century, Marine system engine was launched

1.5.3. Diesel engines were introduced in the 20th century

1.5.4. Marine nuclear reactors were introduced in 1950.

1.5.5. Electric Propulsion motors using battery storage were also used since early 20th century.

1.5.6. Fuel cells and Air Independent Propulsions have been added in 21st century [Psallidas 2010].

1.6. Electric Propulsion

1.6.1. Usage of electric propulsion in underwater platforms e.g., submarines etc started in the beginning of 20th century. An electric propulsion motor driven solely by large capacity batteries as energy source could move the platform slowly due limitation of battery capacity at that time. Also, both its range of operation and time span was limited and therefore bank of batteries with capability to recharge them multiple times were developed. These underwater platforms were mainly powered by combined diesel – electric systems on the surface. During the period of surface operation, batteries were charged and thereafter the platform was deployed for sub surface action for limited duration till batteries lasted.

1.6.2. During World War II, the German Kriegsmarine developed a snorkel system which extended the range and duration of the underwater platform, by allowing the diesel electric system to be utilised while the submarine was underwater. Ultimately, in 1952, the world's first nuclear powered submarines, the USS Nautical, was launched, which removed the limitations of both diesel fuel for Diesel-electric operation and limited period battery propulsion.

1.6.3. The world's first all-electric propulsion driven by battery power without Diesel engine for inland cargo carrier operating in river / sea was constructed by Guangzhou Shipyard International (GSI). This carrier of 2000 dwt can carry bulk cargo up to 40 nautical miles in a single charge of battery [Maritime Executive-2021]. The Cargo Carrier uses lithium-ion batteries (2400 kwh), which are equivalent to the power used by 30 in numbers electric sedan cars of Tesla.

1.7. The details of these propulsion motors and associated controllers are provided in section 3 that deals with description of broad topic. The next section describes the detailed literature of the selected research topic.

2. Literature Review

2.1. Literature presents numerous Electric motors, controllers and their implementations which started in 1831 with Faraday's law of electromagnetic induction. Many of the researchers deliberated about the need of various motors and methods to enhance their design features so that their utilization can be improved. Demand of these motors and controller is continuously increasing ever since the invention of first electric DC motor in 1834 by Thomas Davenport which was battery operated and first AC induction motor by Nikola Tesla in 1887. Invention of alternating current transformer in 1886 extended the reach of single-phase AC to long distances which became a turning point for development of AC equipment. Small wires carried a small current at high voltage to the customer utility, where it was "transformed" to low voltage large current for end equipment. Poly phase alternating current was inaugurated commercially in 1893 and exploited thereafter [C. C. Chesney 1936]. The four laws of Maxwell, later in nineteenth Century have triggered the fast progress of all fundamental electrical machines by 1900. AC power energy system evolved by connecting many generators in parallel by 1930. Last 50 years have seen incredible expansion of generator power, associated units and variable speed AC motor drives in applications with various utilities like ventilators, pumps, compressors, conveyors, transports, mills, electric propulsion systems, robotization, home machines and data – devices etc. This happened due requirement of cleaner energy in the form of electricity which was driven by better material availability, advancement in power electronics, better simulation capability, design methodologies and digital control [I. Boldea 2017]. Naval ships are using motors for propulsion which is called Electric Propulsion System. The HMS Norfolk (F230) is fitted with two DC motors of 1.5MW capacity on the shaft line of the ship with a Combined Diesel Electric and Gas Turbine (CODLAG) propulsion system for propelling the ship [Naval Technology- Type 23 Duke Class 2021]. The U.S. Navy's Zumwalt class Destroyer is fitted with all electric motors for propulsion of the ship [Naval Technology- Zumwalt Class 2021]. The UK Type 26 City class frigate is fitted with a CODLOG arrangement with motor drive for propulsion [G. Allison 2021]. Also, Frigate FFX-II of the Republic of Korean Navy is fitted with modular / compact hybrid Electric Propulsion system of 1.7MW capacity [J. Widmann et al 2019]. It is seen that all these high power drives are being used in the ships

sailing on surface. And, some of these developments have concurrently proliferated in under water platforms also. For Research in Shallow Water, a Turnigy DST-1200, Low power, Brushless motor with three-blade propeller has been used to drive a low cost Robotic Platform [Conte G et al 2020]. For Shipwreck Interior Exploration in submerged state, a Spherical Autonomous Underwater Vehicle uses Four Thruster motors powered by their own 14.8 V, 4000 mAh lithium polymer (LiPo) battery [Ross Eldered et al 2021]. A brushless type permanent magnet DC motor with 16 pole is chosen to generate a maximum of 85N torque at 2000 rpm in the Thruster Design for Unmanned Underwater Vehicles [Çetin Arda Gucer et al 2020]. A Remotely Operated Vessel for Underwater Searching is fitted with six Thruster brushless motors QF-2611 with a rotation of 4500 KV powered by their own 11.1 V, 19,800 mAh lithium Ion battery [Oscar Adrian Aguirre-Castro et al 2019]. Thruster brushless motor with parameter of 110V, 2.5A, 250Hz at Max speed of 6000 r/min accompanied by improved controller with the capability of active disturbance rejection has been used for depth control of Autonomous underwater vehicle [Zhengzheng Zhang et al 2019]. It can be seen that most of the literature brings out comprehensive information on design of low power electric propulsion systems up to a depth of approx 100 meters. **However, detailed information on design of a propulsion motor and associated controller for underwater platform operating at higher depth and power is not available in open literature.** Limited related information available in open literature is given in succeeding paras.

2.2. DC battery operated submarine was launched by Spanish Navy in 1888. First hybrid electric drive submarine, the USS Holand was built in 1900 by US Navy in which propulsion shaft could be powered by engine at the surface and DC motor while submerged. The trend of development extended to present day cruise liners that use Electric podded propulsors which is electric motors located inside the underwater casing (pod /shell) attached to the bottom of the ship. Simultaneously, Motor speed control evolved from inefficient analog resistor control to very efficient Pulse Width Modulation (PWM) [M. Belkhayat 2017]. Podded Propulsors operate at 3.3, 6.6 or 11kV which is not used in submarines and underwater platforms submerged in water due safety requirements [Hansen et al 2015]. Recently, hybrid aerial underwater vehicles have been developed

which can operate in air and surface and dive underwater using propulsion motors operating at 22-25V for exploration and research [Di Lu et al 2020].

2.3. Most of the submarines are propelled by battery operated DC Motors. Operators and Maintainers using these DC motors have been facing challenges due to the presence of brush gear, commutator and sparking at brushes. German Type 212 submarine has a permanent Magnet (PM) Motor which is fitted inside the submarine [Stan Zimmer 2000]. This PMAC motor will be able to provide high power in smaller size by using cooling in the stator winding of PMAC motor. It is seen that the development of efficient, integrated, liquid cooling systems in PM Machines has contributed significantly to the achievement of the highest power and torque densities which enable them for usage in underwater platforms.

2.4. Comparison and Evaluation of Electric Propulsion Motors for submarines was proposed in which propulsion motors based on technology of superconducting homopolar motors, permanent magnet motors and superconducting synchronous motors have been evaluated using repetitive optimisation algorithm for submarine application [Harbour Joel P 2001]. In order to improve performance of propulsion system with 10.8kW Motor for underwater platforms, a counter-rotating two-rotor disc-type PM motor has been proposed [G. Liu et al 2018].

2.5. It is seen from the literature that generally six types of electric propulsion motors can be used in underwater platforms i.e. induction motors, synchronous motors, stepper motors, superconducting homopolar motors, permanent magnet motors and superconducting synchronous motors. All these motors can produce adequate power to drive underwater platforms.

2.6. Underwater Platforms are submerged in water which is a very harsh environment for operation of propulsion motors. When the motor is submerged up to a depth of 1000 meters, the ingress protection needs to be designed so that it can work beyond a pressure of 100kg/cm^2. These motors have to withstand high degree of shock generated by explosion in the sea. Some of the underwater platforms e.g. Submarines, torpedoes etc have a requirement to work in stealth and should not generate noise & vibration otherwise they will be detected and destroyed. Therefore, design of the system has to cater for low

noise & low vibration. Equipment within underwater platforms e.g. controller & other electronics have to be designed to have Electromagnetic Compatibility and avoid electromagnetic interference.

2.7. Various types of motors and associated controllers can be selected based on the attributes e.g. speed for operation of Underwater Platform, location of equipment required (inside/outside) in the underwater platform, shock, noise, vibration, Thermal management, EMI/EMC etc. Motor mounted outside the underwater platform will be submerged in water and should have in built redundancy so that if some phases are not working then also motor should continue to operate with available phases by means of degraded performance. It is found that Multiphase motor will provide such built in redundancy.

2.8. Motors are driven by controllers. One such controller for robust control of sensorless BLDC propulsion motor in submarines for improved movability using an enhanced H infinity approach has been analysed [K. Vinida et al 2016]. H infinity approach using particle swarm optimisation technique in the speed feedback loop has been employed for optimised disturbance rejection. But the same needs to be further augmented for high power multiphase motor. Control tactics belonging to the group of Uninterrupted Control Set - model predictive controls schemes have been experimented up to 6000 rpm for a 6Φ Induction Motor in double 3Φ configuration. However, design for lower speed propulsion motor with inbuilt redundancy has to be explored [A. Tenconi et al 2018].

2.9. Further exploration of technology for controllers reveals that Wide-bandgap (WBG) power semiconductor switches using various materials e.g. silicon carbide (SiC) and gallium nitride (GaN) etc have capability of switching more than ten times faster than their silicon-based equivalents which will help in reducing the size of power converters and streamlining their cooling requirements. This will also help in achieving high reliability with ruggedness for systems that will be possible for all of the modules in the controller electronics to operate for prolonged time periods in harsh thermal, vibration and Electromagnetic environments in underwater platforms with features of advanced diagnostics and fault tolerance [T. M. Jahns et al 2017].

2.10. A detailed literature survey reveals that propulsion motor fitted outside the underwater platform and associated controller needs to be designed to meet the attributes of underwater platform and drive it to operate in submerged state up to depth of 1000 meters and provide 1MW output of shaft power for the propeller. Detailed review of various design technique to achieve abovementioned parameters will be specified. Each technique has some advantages and some disadvantages. Selection of design technique is dependent on the attributes of underwater platform and by using different techniques, design can be optimized. No such design for motor operating at 1000 meters of depth is available in open literature and therefore**, propulsion motor and associated controller for underwater platforms is still the open research area**.

2.11. **Gaps in Literature**.

Following gaps are found in literature for propulsion motor and associated controller for underwater platforms: -

2.11.1. Design for high power multiphase propulsion motor mounted outside the underwater platform and submerged in water and associated controller is not available.

2.11.2. Design for high power multiphase propulsion motor and associated controller for high shock, low noise, low vibration and EMI/EMC compliant requirement is not available.

2.11.3. Such propulsion motor and associated controllers are not designed and manufactured in India.

2.11.4. Propulsion motors may be available outside India e.g. Russia, France, Germany, USA etc but associated information is not published in open literature.

3. Description of Topic

3.1. In this research, a multiphase electric propulsion motor for underwater platform will be designed. This will be a variable speed motor with a maximum speed of 800 revolutions per minute. The motor will generate a maximum shaft torque of 1MW at 800 rpm for propeller to drive the Underwater Platform. The torque and associated rotational speed of the motor can be varied to meet the motion / thrust requirement of the underwater

platform by controller which will get 415V, 50Hz, 3Φ AC (Standard 3 Phase supply in India) from generator or 190-280 V DC from Battery banks. Two such motors mounted outside the underwater platform on port and starboard (stbd) side will operate it when submerged in water. The motors will be designed to operate in underwater / ocean up to a depth of 1000 meters. Both motors will be able to drive the underwater platform of 18000 dwt with an approximate speed of six knots depending upon the design of outer structure of underwater platform and propeller. Therefore, these motors can be used for slow motion of the underwater platform. In case higher speed of the underwater platform is required, then capacity of the motor will have to be enhanced and accordingly, higher power motor will have to be designed. Propulsion motors mounted outside the underwater platform have to be highly reliable because these motors cannot be repaired in-situ while submerged in water. Therefore, these motors should have in built redundancy e.g. in case, few phases of multiphase propulsion motor are not working then multiphase motor should continue to operate with available phases by means of degraded performance.

3.2. Multiphase electric propulsion motor will be operated through controller of required capacity. This controller will generate variable frequency and variable voltage to ensure that torque requirement generated at motor shaft can drive the underwater platform. The controller will be designed with redundancy to ensure availability of power supply to individual phases of motor operating submerged in water.

3.3. The controller will be mounted inside the underwater platform and therefore it will be designed for ingress protection of IP 44. Whereas, multiphase propulsion motor will be mounted outside the underwater platform submerged in water and therefore it will be designed for ingress protection of IP 68 up to a depth of 1000 meters.

3.4. Propulsion motor will be mounted outside the platform in a hinged support so that it can be retracted when not in use. This retraction will provide smooth movement and reduction in drag of underwater platform when these motors are not being used for propulsion. Whenever these motors are required to be used for propulsion, they will be opened with the help of hydraulic system like landing gear of an aircraft.

3.5. The input power supply to the controller will be 415V, 50Hz, 3Φ AC (Standard 3 Phase supply in India) or 190-280 V DC. AC Supply will be given from the generators

installed onboard underwater platforms. DC supply will be given from the bank of batteries and therefore voltage will vary depending on the charged state of cells / batteries. Front end converter and booster will be designed in controller to meet variable power supply requirements.

3.6. Multiphase propulsion motor and associated controller will be designed for high shock, low noise, low vibration, thermal management and EMI/EMC compliant requirement for usability in underwater platform. Also, remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt will be implemented.

4. Objectives of the Research

4.1. Problem Formulation

Multiphase propulsion Motor and Associated controller motor needs to be designed which can work in submerged state up to a depth of 1000 meters and provide 1MW output of shaft torque at 800 rpm for the propeller to drive the Underwater Platform. Also, motor should be operated remotely from Underwater Platform Management System through controller using IEEE802.3 bt network.

4.2. Objectives of the research shall be following for design of propulsion motor and associated controllers for Underwater Platforms using necessary software tools as applicable: -

4.2.1. To explore different types of propulsion motors operating at variable speed while submerged in water and different types of controllers for multiphase motors.

4.2.2. To develop and implement design of multiphase propulsion motor operating at variable speed while submerged in water with improved redundancy.

4.2.3. To develop algorithm for improved redundancy in the design of controller and implement the optimised controller for multiphase propulsion motor.

4.2.4. To determine performance of multiphase propulsion motor and associated controller for designed torque.

4.2.5. To implement remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt.

4.2.6. To evaluate performance of developed multiphase propulsion motor and associated controller for underwater platform by using different parameters like torque generated at shaft of the rotor, efficiency, shock withstandability, vibration generated by motor and EMI/EMC compliance.

5. Methodology

5.1. The proposed methodology firstly starts with exploration of different types of propulsion motors operating at variable speed while submerged in water. After doing a comparative analysis of these motors, a multiphase motor with a maximum speed of 800 rpm and IP68 up to 1000 meters submergence will be designed and implemented. Design of multiphase motor will be optimised to provide redundancy in case of failure of few phases of motor. This iterative process of design will be further optimised for operation with 415V, 50Hz, 3Φ AC from Generators or 190-280 V DC from batteries / DC generators.

5.2. The second phase will start with exploration of different types of controllers for multiphase motors. Thereafter algorithm for improved redundancy in controller will be formulated and optimised controller will be implemented. This will be followed by determination of performance of multiphase propulsion motor and associated controller for designed torque. The performance of implemented system will be evaluated by using different parameters like torque generated at the shaft of rotor, efficiency, shock withstandability, vibration generated by motor and EMI/EMC compliance. All activities mentioned above will be carried out using necessary software tools as applicable. The flowchart of proposed methodology is presented in figure 3 below:

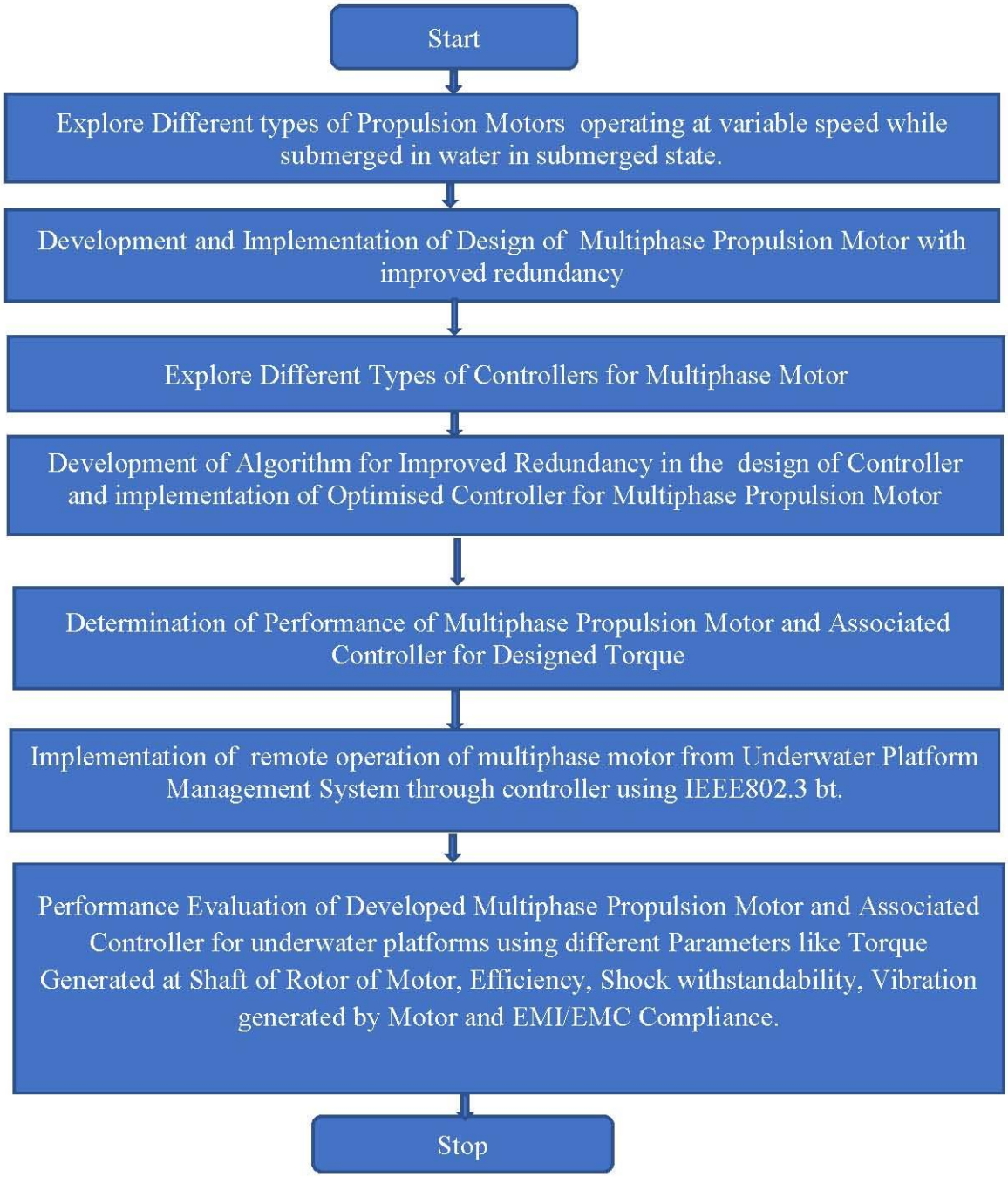
Start
Explore Different types of Propulsion Motors operating at variable speed while submerged in water in submerged state.
Development and Implementation of Design of Multiphase Propulsion Motor with improved redundancy
Explore Different Types of Controllers for Multiphase Motor
Development of Algorithm for Improved Redundancy in the design of Controller and implementation of Optimised Controller for Multiphase Propulsion Motor
Determination of Performance of Multiphase Propulsion Motor and Associated Controller for Designed Torque
Implementation of remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt.
Performance Evaluation of Developed Multiphase Propulsion Motor and Associated Controller for underwater platforms using different Parameters like Torque Generated at Shaft of Rotor of Motor, Efficiency, Shock withstandability, Vibration generated by Motor and EMI/EMC Compliance.
Stop

Figure 3: Methodology

5.3. **Step (1).** Exploration of different types of Propulsion Motors fitted outside the underwater platform and operating in submerged state will be carried out. Implementation of multiphase propulsion motor will take place by selecting the appropriate stator, rotor, and

associated components. Methodology of its operation at a submerged depth of 1000 meters will be worked out which will include pressure compensation system, sealing arrangement etc.

5.4. **Step (2).** Multiphase motors work on a concept of independent torque generation through a drive. If one phase fails due some reason then that phase is not supplied with power by the controller. Balance phases are re-sequenced and motor continues to rotate and generate lesser torque with graceful degradation of performance. Technique for Improved redundancy in Multiphase Motor will be finalized.

5.5. **Step (3).** Different Types of Controllers for Multiphase Motor will be explored. Controller for multiphase motor will be designed and algorithm for improved redundancy will be optimised and implemented.

5.6. **Step (4).** Methodology for determination of Performance of Multiphase Propulsion Motor and Associated Controller for Designed shaft Torque / power will be established**.**

5.7. **Step (5).** Implementation of remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt.

5.8. **Step (6).** Performance Evaluation of Developed Multiphase Propulsion Motor and Associated Controller will be carried out using different Parameters like Torque Generated at the Shaft of Rotor, Efficiency, Shock withstandability, Vibration generated by Motor and EMI/EMC Compliance.

5.9. **Step (7).** All points mentioned above will be revisited, in case performance is sub-optimal. Design will be changed to get optimum performance mentioned above.

5.10. **Step (8).** Develop and finalise the Design of a Propulsion Motor and Associated Controller for Underwater Platform and publish the report.

6. Expected Outcome of the Research

6.1. Design Capability of a Propulsion motor and associated controller for underwater platform in India.

6.2. Simulation Methodology of the adopted techniques for above mentioned design using Software tools

7. Proposed Time Frame

Time Frame	Aug 18-Jun 19	Jul 19-Jun 20	Jul 20-Jun 21	Jul 21-Dec 21	Jan 22-Jun 22	Jul 22-Dec 22	Jan 23-Dec 23
Course Work							
Extensive Literature Survey							
Problem Statement Formulation							
Publication on Literature Survey							
Explore Different types of propulsion Motor operating at variable speed while submerged in water							
Implementation of Design of Multiphase Propulsion Motor operating at variable speed while submerged in water							
Technique for Improved redundancy in Multiphase Motor							
Explore Different Types of Controllers for Multiphase Motor							
Algorithm for Improved Redundancy in Controller							
Determination of Optimised Controller for Multiphase Propulsion Motor							
Determination of Performance of Multiphase Propulsion Motor and Associated Controller for Designed Torque							
Implementation of remote operation of multiphase motor from Underwater Platform Management System through controller using IEEE802.3 bt							
Performance Evaluation of Developed Multiphase Propulsion Motor and Associated Controller using different Parameters like Torque Generated at Shaft of Rotor, Efficiency, Shock withstandability, Vibration generated by Motor and EMI/EMC Compliance							
Develop Design of a Propulsion Motor and Associated Controller for Underwater Platform.							
Publication on obtained results							
Thesis Submission							

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